Sensors **2011**, *11*, 11273-11294; doi:10.3390/s111211273

OPEN ACCESS

sensors

ISSN 1424-8220

www.mdpi.com/journal/sensors

Article

Modeling and Analysis of an Energy-Efficient Mobility Management Scheme in IP-Based Wireless Networks †

Ho Young Hwang [1], Sun-Jong Kwon [2], Yun Won Chung [3], Dan Keun Sung [4] and Suwon Park [5,⋆]

[1] Department of Computer Engineering, Kwangwoon University, Seoul 139-701, Korea; E-Mail: hyhwang@kw.ac.kr

[2] Central R&D Laboratory, KT, Seoul 137-792, Korea; E-Mail: sunjong.kwon@kt.com

[3] School of Electronic Engineering, Soongsil University, Seoul 156-743, Korea; E-Mail: ywchung@ssu.ac.kr

[4] Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Korea; E-Mail: dksung@ee.kaist.ac.kr

[5] Department of Electronics and Communications Engineering, Kwangwoon University, Seoul 139-701, Korea

† This work was presented in part at the *Global Telecommunications Conference (GLOBECOM) 2002*, Taipei, Taiwan, 17–21 November 2002, and *Future Generation Information Technology (FGIT) 2010*, Jeju Island, Korea, 13–15 December 2010.

⋆ Author to whom correspondence should be addressed; E-Mail: spark@kw.ac.kr; Tel.: +82-2-940-5139; Fax: +82-2-909-5441.

Received: 11 October 2011; in revised form: 7 November 2011 / Accepted: 21 November 2011 / Published: 28 November 2011

Abstract: An energy-efficient mobility management scheme in IP-based wireless networks is proposed to reduce the battery power consumption of mobile hosts (MHs). The proposed scheme manages seven MH states, including transmitting, receiving, attention/cell-connected, attention/paging area(PA)-connected, idle, off/attached, and detached states, to efficiently manage battery power, radio resources, and network load. We derive the stationary probabilities and steady state probabilities of the seven MH states for the proposed scheme in IP-based wireless networks in compact form. The effects of various input parameters on MH steady state probabilities and power consumption are investigated in the proposed scheme compared to the conventional scheme. Network costs such as cell updates, PA updates, binding-lifetime-based registrations, and paging messages are analyzed in the proposed and conventional schemes. The optimal values of PA size

and registration interval are derived to minimize the network cost of the proposed scheme. The combined network and power costs are investigated for the proposed and conventional schemes. The results provide guidelines to select the proper system parameters in IP-based wireless networks.

Keywords: energy-efficient mobility management; steady state analysis; Mobile IP

1. Introduction

Wireless networks and systems have evolved toward an IP-based network architecture. In such networks and systems, mobility needs to be handled at the IP layer based on the Internet Engineering Task Force (IETF) concept. Many IP-based mobility protocols, such as Mobile IPv4 (MIPv4) [1], Mobile IPv6 (MIPv6) [2], and IP micro-mobility protocols (e.g., Cellular IP [3] and HAWAII [4]) have been proposed and studied. MIPv4 [1] and MIPv6 [2] do not distinguish *idle* mobile hosts (MHs) from *active* MHs. These MIP protocols support registration but not paging. Hence, a care-of-address (CoA) needs to be updated whenever an MH moves to a different subnet which is served by a different foreign agent (FA) in the MIPv4 [1] or by a different access router (AR) in the MIPv6 [2] without regard to the MH states, *i.e.*, *active* and *idle*. This results in a significant waste of the MH battery power and an unnecessary signaling load because it is expected that wireless IP users are not actively communicating most of the time.

Various schemes on IP paging services for MHs have been studied. The P-MIP [5-6] is an extension to MIP which is proposed to reduce the signaling load in the core Internet. In this scheme, two MH states, *i.e.*, *active* and *idle*, were defined. In the *active* state of an MH, registration occurs whenever the MH changes its cell. On the other hand, in the *idle* state of an MH, a registration occurs only if the MH changes its paging area (PA). When there are any incoming data for the *idle* MH, paging is performed in order to find the exact location of the called MH.

Many enhancements for the MIP protocols, such as hierarchical Mobile IPv6 (HMIPv6) [7] and fast handover for Mobile IPv6 (FMIPv6) [8], have been investigated. Recently, the IETF Network-based Localized Mobility Management (NETLMM) working group proposed the NETLMM protocol [9-10]. The Proxy Mobile IPv6 (PMIPv6) [11] was also developed by the IETF NETLMM working group. In PMIPv6, the network supports IP mobility management on behalf of the MHs. Qualitative and quantitative comparisons between MIPv6 and PMIPv6 have been investigated by Kong *et al.* [12]. The PMIPv6-based global mobility management architecture and protocol procedure known as GPMIP was presented by Zhou *et al.* [13].

In our earlier study [14], we proposed a mobility management scheme that considered the *detached* and *off* states for IP-based mobile networks. We analyzed an optimal rate of binding-lifetime (BL)-based registrations which yields a minimum network cost when the registrations are utilized as a means of identifying the *off* state of MHs. To reduce MH power consumption, it is important to manage the *idle* MH state in the mobility management scheme for an efficient battery power management of MHs. In many IP-based mobility management schemes including that in our earlier study, MHs perform a

PA-based registration in the *idle* or *dormant* state. However, to operate the MHs as a fully power-saving mode in the *idle* or *dormant* state, the state for the PA-based registration may need to be distinguished from the *idle* or *dormant* state.

In our earlier study [15], we proposed six MH states in which the communicating state was not divided into transmitting and receiving states. We derived the state transition probabilities and mean sojourn times in six MH states, and analyzed the effects of parameters based on simple exponential distribution assumed on session holding time and binding-lifetime. In our recent study [16], we derived the stationary probabilities and steady state probabilities of the proposed six MH states. The effects of session holding time on MH steady state probabilities and power consumption were investigated. We considered more practical distributions, *i.e.*, Erlang and Gamma distributions, on session holding time.

In this paper, we propose an energy-efficient mobility management scheme for reducing MH power consumption in IP-based wireless networks. The proposed scheme manages seven MH states, including transmitting, receiving, attention/cell-connected, attention/PA-connected, idle, off/attached, and detached states, to efficiently manage battery power, radio resources, and network load. To compare the power-saving effect of the proposed scheme with that of the conventional scheme, we derive the stationary probabilities and steady state probabilities of both the proposed scheme with the seven MH states and the conventional scheme for Mobile IP-based wireless networks in compact form. The effects of various input parameters on MH steady state probabilities and power consumption are investigated in both the proposed scheme and conventional scheme with consideration of exponential and fixed distributions on the interval of BL-based registration. Network costs such as cell updates, PA updates, binding-lifetime-based registrations, and paging messages are analyzed in the proposed and conventional schemes. The effects of various input parameters on the network costs for the proposed and conventional schemes are investigated. The optimal values of PA size and registration interval are derived to minimize the network cost of the proposed scheme. We also investigate the combined network and power cost for the proposed and conventional schemes using various weighting factors. These analytical results provide guidelines to select the proper system parameters. The results can be utilized to analyze the performance of mobility management schemes in IP-based wireless networks.

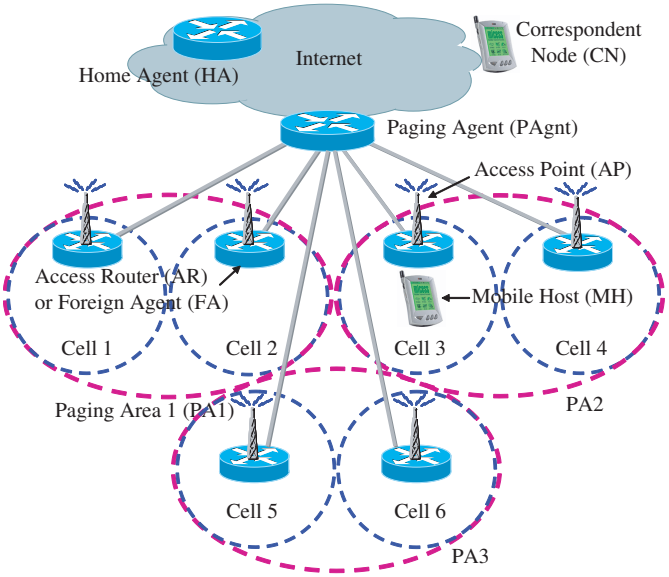
This paper is organized as follows: An IP-based wireless network architecture and an energy-efficient mobility management scheme are presented in Section 2. The MH state transitions are modeled, and the stationary probabilities and steady state probabilities of the seven MH states are analyzed. The MH energy consumptions as well as the network costs for both the proposed and conventional schemes are analyzed. The optimal values of PA size and registration interval are derived to minimize the network cost in Section 3. Numerical examples are used to investigate the MH steady state probabilities, the power saving effect, and the network costs compared with the conventional scheme for Mobile IP-based wireless networks in Section 4. Finally, conclusions are presented in Section 5.

2. IP-Based Wireless Network Architecture and MH State Transition Model

An IP-based wireless network architecture is shown in Figure 1 [15]. An access router (AR) provides MHs with IP connectivity. The AR acts as a default router to the currently served MHs. Since MIPv6 [2] provides many advantages over MIPv4 [1], MIPv6 [2] is considered a reference mobility protocol in this paper. However, we note that the proposed scheme can be applied to both the MIPv4 and MIPv6-based

wireless networks. An energy-efficient mobility management scheme is proposed to manage the following seven MH states: transmitting, receiving, attention/cell-connected, attention/PA-connected, idle, off/attached, and detached states. Transmitting, receiving, and attention/cell-connected MHs behave in the same manner as MIP. The correspondent node (CN) and home agent (HA) do not need to be changed. The MH and paging agent (PAgnt) require only minor changes. The PAgnt conducts paging-related functions and manages one or more PAs. Two or more ARs can exist in a PA. To establish the PA identity, a unique PA identifier (PAI) can be used.

Figure 1. An IP-based wireless network architecture.



A transmitting, receiving, or attention/cell-connected MH registers its collocated care-of address (CCoA) at the corresponding HA as in MIP. Hence, the PAgnt does not need to be involved in the MIP registration procedure. When a transmitting, receiving, or attention/cell-connected MH moves to a different cell which is served by a different AR, the MH conducts cell-based registration in the same manner as the MIP registration. After the data session is completed, the MH enters the attention/cell-connected state and an attention timer is reset and restarted. The attention timer is used to decide the instant when the MH enters the idle state. If the attention timer expires, an attentive MH that is in the attention/cell-connected state or attention/PA-connected state enters the idle state by conducting PA-based registration. Through this PA-based registration, the MH can register a PAI of the current PA at the PAgnt. A paging agent care-of address (PAgnt-CoA) of the current PAgnt is registered at the corresponding HA of the MH. Whenever an idle MH moves to a different PA or PAgnt, the MH enters the attention/PA-connected state to conduct the PA-based registration and the attention timer is reset and restarted.

When data packets which are destined for an idle MH arrive at the HA, the packets are tunneled to the PAgnt. Hence, the HA is unaware of the idle state of the MH. The PAgnt buffers the data packets and sends paging request messages to ARs in the PA. The signaling messages can be sent to MHs via access points which are connected to the ARs. The corresponding idle MH enters the receiving state,

and sends paging reply messages to the PAgnt. Concurrently, the MH registers its CCoA at the HA as the MIP registration. The PAgnt can forward the buffered data packets.

The MH power-off state can be detected by a BL-based registration and an unsuccessful paging. When the HA or the PAgnt sets a limitation on the maximum binding lifetime, the BL-based registration can be used to detect the power-off state of MHs. The network considers the MH state as detached when it detects a silence for more than an agreed time period or the MH does not respond to paging.

In the proposed scheme, an MH has the following seven states:

(1) Transmitting: The MH registers its CCoA at the corresponding HA as MIP. In this state, the MH has outgoing sessions. The MH remains during the session holding time. The MH exits this state upon completing outgoing data sessions or a switch-off action.
(2) Receiving: After the MH registers its CCoA at the corresponding HA as in MIP, the MH can receive the data packets. An exit from this state is caused by incoming session completion or switch-off action.
(3) Attention/cell-connected: There is no incoming or outgoing session for the MH. The MH conducts a cell-based registration whenever it enters this state from the off/attached state or detached state or it changes its serving AR. Thus, the MH location is known in the network with cell accuracy. When an incoming or outgoing session arrives, the MH enters the transmitting or receiving state. When an attention timer expires, the MH enters the idle state by performing a PA-based registration.
(4) Attention/PA-connected: The MH conducts the PA-based registration. Thus, the MH location is known in the network with PA accuracy. When an attention timer expires, the MH reenters the idle state. When an incoming or outgoing session arrives, the MH enters the communicating state. If the MH is switched off, it enters the off/attached state.
(5) Idle: The MH is not currently involved in ongoing sessions and signaling messages. Thus, the idle MH can operate in a power-saving mode. When the idle MH moves to a different PA or PAgnt, the MH enters the attention/PA-connected state to perform the PA-based registration. When an MH is in the idle state, its current location information is maintained in terms of PA.
(6) Off/attached: If the MH is powered off, the PAgnt is not immediately informed of the power-off state. The power-off state can be detected by a BL-based registration and an unsuccessful paging. When the binding-lifetime expires or paging is unsuccessful, the network detaches the MH. When the MH is switched on, it enters the attention/cell-connected state by performing the MIP registration.
(7) Detached: If the network detects an MH switch-off action, it detaches the MH. The MH neither responds to paging nor sends location registration messages.

3. Analysis of an Energy-Efficient Mobility Management Scheme

3.1. Stationary Probabilities and Steady State Probabilities

We derive the stationary probabilities and steady state probabilities of seven MH states for the proposed energy-efficient mobility management scheme in IP-based wireless networks in

compact form. MH state transitions are shown in Figure 2. We assume the following density functions of random variables:

- Incoming (receiving) and outgoing (transmitting) sessions occur at an MH according to a Poisson process with parameters λ_i and λ_o, respectively.
- The cell and PA residence durations are exponentially distributed with parameters $1/\lambda_c$ and $1/\lambda_{PA}$, respectively.
- Switch-off actions take place according to a Poisson process with a parameter of λ_{off}.
- The duration that an MH remains switched-off follows an exponential distribution with a parameter of $1/\mu_{off}$.

Since the residence time of the MH in each state is not exponentially distributed, we analyze the MH state transitions using a semi-Markov process approach [15-17]. The stationary probabilities of the imbedded Markov chain are obtained by solving the balancing equations:

$$\pi_j = \sum_{i=1}^{7} \pi_i P_{ij}, \qquad j = 1, 2, ..., 7 \tag{1}$$

$$1 = \sum_{i=1}^{7} \pi_i \tag{2}$$

where π_i denotes the stationary probability of state i while P_{ij} denotes the state transition probability from state i to state j. The state transition probability matrix $P = [P_{ij}]$ for the MH state transitions is expressed as:

$$P = \begin{pmatrix} 0 & 0 & P_{13} & 0 & 0 & P_{16} & 0 \\ 0 & 0 & P_{23} & 0 & 0 & P_{26} & 0 \\ P_{31} & P_{32} & 0 & 0 & P_{35} & P_{36} & 0 \\ P_{41} & P_{42} & 0 & 0 & P_{45} & P_{46} & 0 \\ P_{51} & P_{52} & 0 & P_{54} & 0 & P_{56} & 0 \\ 0 & 0 & P_{63} & 0 & 0 & 0 & P_{67} \\ 0 & 0 & P_{73} & 0 & 0 & 0 & 0 \end{pmatrix} \tag{3}$$

From Equations (1–3) the stationary probabilities of the seven MH states are solved as:

$$\pi_1 = \frac{1}{D}\Big[\{(P_{31}(1 - P_{45}P_{54}) + P_{35}(P_{41}P_{54} + P_{51})\}(P_{63} + P_{73}P_{67})\Big] \tag{4}$$

$$\pi_2 = \frac{1}{D}\Big[\{(P_{32}(1 - P_{45}P_{54}) + P_{35}(P_{42}P_{54} + P_{52})\}(P_{63} + P_{73}P_{67})]\Big] \tag{5}$$

$$\pi_3 = \frac{1}{D}\Big[(1 - P_{45}P_{54})(P_{63} + P_{73}P_{67})\Big] \tag{6}$$

$$\pi_4 = \frac{1}{D}\Big[P_{35}P_{54}(P_{63} + P_{73}P_{67})\Big] \tag{7}$$

$$\pi_5 = \frac{1}{D}\Big[P_{35}(P_{63} + P_{73}P_{67})\Big] \tag{8}$$

$$\pi_6 = \frac{1}{D}\Big[(1-P_{13}P_{31}-P_{23}P_{32})(1-P_{45}P_{54})-P_{13}P_{35}(P_{51}+P_{41}P_{54})-P_{23}P_{35}(P_{52}+P_{42}P_{54})\Big] \tag{9}$$

$$\pi_7 = \frac{1}{D}\Big[P_{67}\{(1-P_{13}P_{31}-P_{23}P_{32})(1-P_{45}P_{54})-P_{13}P_{35}(P_{51}+P_{41}P_{54})-P_{23}P_{35}(P_{52}+P_{42}P_{54})\}\Big] \tag{10}$$

where D consists of the state transition probabilities P_{ij}.

The steady state probabilities of the semi-Markov process are obtained by:

$$P_i = \frac{\pi_i \bar{T}_i}{\sum_{j=1}^{7} \pi_j \bar{T}_j}, \quad i = 1, 2, ..., 7 \tag{11}$$

where the values of the mean sojourn times of the MH in each state i, $\bar{T}_i$ are expressed as [15]:

$$\bar{T}_1 = \frac{1 - F_s^*(\lambda_{off})}{\lambda_{off}}, \qquad \bar{T}_2 = \frac{1 - F_s^*(\lambda_{off})}{\lambda_{off}} \tag{12}$$

$$\bar{T}_3 = \frac{1 - e^{-(\lambda_i+\lambda_o+\lambda_{off}+\lambda_c)T_A}}{\lambda_i + \lambda_o + \lambda_{off} + \lambda_c e^{-(\lambda_i+\lambda_o+\lambda_{off}+\lambda_c)T_A}}, \qquad \bar{T}_4 = \frac{1 - e^{-(\lambda_i+\lambda_o+\lambda_{off})T_A}}{\lambda_i + \lambda_o + \lambda_{off}} \tag{13}$$

$$\bar{T}_5 = \frac{1 - F_r^*(\lambda_i+\lambda_o+\lambda_{off}+\lambda_{PA})}{\lambda_i + \lambda_o + \lambda_{off} + \lambda_{PA}}, \qquad \bar{T}_6 = \frac{1}{\lambda_i+\mu_{off}}\{1-\frac{\lambda_r}{\lambda_i+\mu_{off}}[1-F_r^*(\lambda_i+\mu_{off})]\} \tag{14}$$

$$\bar{T}_7 = \frac{1}{\mu_{off}} \tag{15}$$

The steady state probabilities of the seven MH states for the proposed scheme are derived in compact form as [16]:

$$P_1 = \frac{\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{\lambda_o(1 - F_s^*(\lambda_{off}))}{\lambda_s + \lambda_{off}} \left[1 - \frac{\lambda_s}{\lambda_s + \lambda_{off}} F_s^*(\lambda_{off})\right]^{-1} \tag{16}$$

$$P_2 = \frac{\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{\lambda_i(1 - F_s^*(\lambda_{off}))}{\lambda_s + \lambda_{off}} \left[1 - \frac{\lambda_s}{\lambda_s + \lambda_{off}} F_s^*(\lambda_{off})\right]^{-1} \tag{17}$$

$$P_3 = \frac{\lambda_{off}\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{1 - e^{-\lambda_2}}{\lambda_1 + \lambda_c e^{-\lambda_2}} \left[1 - \frac{\lambda_s}{\lambda_s + \lambda_{off}} F_s^*(\lambda_{off})\right]^{-1} \tag{18}$$

$$P_4 = \frac{\lambda_{off}\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{\lambda_1 F_r^*(\lambda_1 + \lambda_{PA}) + \lambda_{PA}}{\lambda_1[1 - e^{-\lambda_3} F_r^*(\lambda_1 + \lambda_{PA})] + \lambda_{PA}(1 - e^{-\lambda_3})} \cdot \frac{(\lambda_1 + \lambda_c)(1 - e^{-\lambda_3})e^{-\lambda_2}}{\lambda_1(\lambda_1 + \lambda_c e^{-\lambda_2})} \left[1 - \frac{\lambda_s}{\lambda_s + \lambda_{off}} F_s^*(\lambda_{off})\right]^{-1} \tag{19}$$

$$P_5 = \frac{\lambda_{off}\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{1 - F_r^*(\lambda_1 + \lambda_{PA})}{\lambda_1[1 - e^{-\lambda_3} F_r^*(\lambda_1 + \lambda_{PA})] + \lambda_{PA}(1 - e^{-\lambda_3})} \cdot \frac{(\lambda_1 + \lambda_c)e^{-\lambda_2}}{\lambda_1 + \lambda_c e^{-\lambda_2}} \left[1 - \frac{\lambda_s}{\lambda_s + \lambda_{off}} F_s^*(\lambda_{off})\right]^{-1} \tag{20}$$

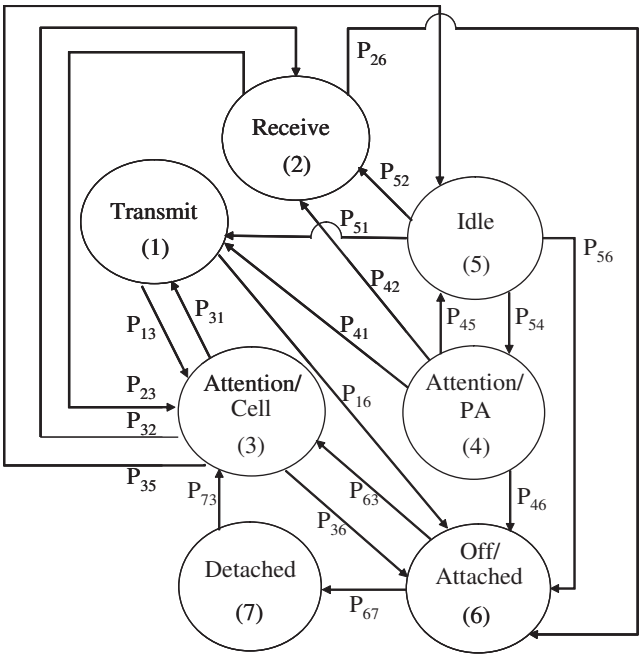
$$P_6 = \frac{1}{\lambda_i + \mu_{off}} \frac{\lambda_{off}\mu_{off}}{\lambda_{off} + \mu_{off}} \left[1 - \frac{\lambda_r}{\lambda_i + \mu_{off}}(1 - F_r^*(\lambda_i + \mu_{off}))\right] \tag{21}$$

$$P_7 = \frac{1}{\lambda_i + \mu_{off}} \frac{\lambda_{off}}{\lambda_{off} + \mu_{off}} \left[\lambda_i + \frac{\lambda_r \mu_{off}}{\lambda_i + \mu_{off}}(1 - F_r^*(\lambda_i + \mu_{off}))\right] \tag{22}$$

where $\lambda_1 = \lambda_i + \lambda_o + \lambda_{off}$, $\lambda_2 = (\lambda_1 + \lambda_c)T_A$, $\lambda_3 = \lambda_1 T_A$, $\lambda_s = \lambda_i + \lambda_o$. λ_i denotes the mean arrival rate of incoming sessions, λ_o denotes the mean arrival rate of outgoing sessions, $1/\lambda_c$ denotes the mean cell residence duration, $1/\lambda_{PA}$ denotes the mean PA residence duration, λ_{off} denotes the mean switch-off rate, $1/\mu_{off}$ denotes the mean switch-off duration, and T_A denotes the attention timer value. The session holding time is assumed to follow a general distribution with a density function $f_s(t)$ with a mean $1/\mu_s$ while $F_s^*(\theta)$ is the Laplace transform of $f_s(t)$. Since the Gamma distribution has the same trend as a Pareto distribution in terms of variance impact, it is useful for data packet transmission times [18-21].

The Erlang and Gamma distributions can be used for the session holding time. The interval of BL-based registration is assumed to follow a general distribution with a density function $f_r(t)$ with a mean of $1/\lambda_r$ while $F_r^*(\theta)$ is the Laplace transform of $f_r(t)$.

Figure 2. The mobile host (MH) state transitions.



3.2. The Power-Saving Effect

The power-saving effect of the proposed scheme is analyzed compared to the conventional scheme for Mobile IP-based wireless networks. To analyze the power-saving effect, let Pc_i denote power consumption in state i. The energy consumption for the proposed scheme is obtained by:

$$E_{prop} = \sum_{i=1}^{5} Pc_i P_i t \tag{23}$$

When an *idle* MH moves to a different PA or PAgnt, the MH enters the *attention/PA-connected* state to perform the PA-based registration. The *idle* MH enters the *communicating* state when either an incoming or outgoing session arrives. Thus, the *idle* MH can operate in a power-saving mode since the *idle* MH may not have communicating sessions or signaling messages. The power consumption in each state of the MH has the following condition:

$$Pc_1 \geq Pc_2 \geq Pc_3 \geq Pc_4 \gg Pc_5 \tag{24}$$

Since the conventional MIP protocol [1-2] supports registration but not paging, it does not distinguish active MHs from idle ones. Hence, the value of the attention timer T_A approaches ∞. Therefore, the steady state probabilities for the conventional MIP scheme are expressed as:

$$\lim_{T_A\to\infty} P_1 = P_1, \quad \lim_{T_A\to\infty} P_2 = P_2$$
$$\lim_{T_A\to\infty} P_3 = [1 - \frac{\lambda_s}{\lambda_s + \lambda_{off}} F_s^*(\lambda_{off})]^{-1} \frac{\lambda_{off}\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{1}{\lambda_1}$$
$$\lim_{T_A\to\infty} P_4 = 0, \quad \lim_{T_A\to\infty} P_5 = 0$$
$$\lim_{T_A\to\infty} P_6 = P_6 = \frac{\lambda_{off}\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{1}{\lambda_i + \mu_{off}} [1 - \frac{\lambda_r}{\lambda_i + \mu_{off}} (1 - F_r^*(\lambda_i + \mu_{off}))]$$
$$\lim_{T_A\to\infty} P_7 = P_7 = \frac{\lambda_{off}}{\lambda_{off} + \mu_{off}} \frac{1}{\lambda_i + \mu_{off}} [\lambda_i + \frac{\lambda_r\mu_{off}}{\lambda_i + \mu_{off}} (1 - F_r^*(\lambda_i + \mu_{off}))]$$

Then, the energy consumption for the conventional MIP scheme is obtained by:

$$\begin{aligned} E_{conv} &= \lim_{T_A\to\infty} \sum_{i=1}^{5} Pc_i P_i t = (Pc_1 P_1 + Pc_2 P_2 + Pc_3 \lim_{T_A\to\infty} P_3)t \\ &= \{Pc_1 P_1 + Pc_2 P_2 + Pc_3 (P_3 + P_4 + P_5)\}t \end{aligned} \quad (25)$$

From Equations (23–25), the relationship of the energy consumption between the proposed and conventional schemes is expressed as $E_{prop} \leq E_{conv}$. Therefore, the energy consumption for the proposed scheme is always lower than that for the conventional scheme. Additionally, the proposed scheme with a proper value of attention timer T_A yields significant power savings compared with the conventional mobility management scheme for Mobile IP-based wireless networks.

3.3. Network Cost

We analyze the network cost due to registration and paging messages using the steady state probabilities. When an MH is in the *transmitting*, *receiving* or *attention/cell-connected* state, the MH performs a cell-based registration. If an MH is in the *attention/PA-connected* or *idle* state, the MH performs a PA-based registration, and the system can page the MH if data packets are destined for the MH. If an MH is not switched off, it performs a BL-based registration.

Let ρ_{MH} and A_{tot} denote the density of MHs within a total area and the size of the total area, respectively. The rates of cell-based registration, PA-based registration, BL-based registration, and paging messages for the proposed scheme are expressed as:

$$\lambda_{prop}^{cell} = \rho_{MH} A_{tot} (P_1 + P_2 + P_3)\lambda_c \quad (26)$$
$$\lambda_{prop}^{PA} = \rho_{MH} A_{tot} (P_4 + P_5)\lambda_{PA} = \rho_{MH} A_{tot} (P_4 + P_5)\lambda_c / \sqrt{N_{cell/PA}} \quad (27)$$
$$\lambda_{prop}^{BL} = \rho_{MH} A_{tot} \sum_{i=1}^{5} P_i \frac{\bar{N}_{BL,i}}{\bar{T}_i} \quad (28)$$
$$\lambda_{prop}^{pag} = \rho_{MH} A_{tot} (P_4 + P_5 + kP_6)\lambda_i N_{cell/PA} \quad (29)$$

where $N_{cell/PA}$ is the number of cells in PA, $\bar{N}_{BL,i}$ is the mean number of BL-based registrations during the mean sojourn time in state i, and k is the number of paging repetitions when the paging is unsuccessful. In Equation (27), λ_{PA} is expressed with λ_c and $N_{cell/PA}$ under the assumptions of a square shaped configuration of cell and PA, and a fluid flow mobility model of MHs [5], [22]. In Equation (29), λ_{prop}^{pag} is expressed with $N_{cell/PA}$ because an additional paging cost is incurred as different cells in PA transmit the same paging messages.

We consider that MHs move at an average speed of V_i according to the environment type which consists of stationary user environment ($i = 0$), urban in-building environment ($i = 1$), urban pedestrian environment ($i = 2$), and urban vehicular environment ($i = 3$) [23-25]. It is considered that MHs move in directions which are uniformly distributed over $[0, 2\pi]$, and the MHs are uniformly distributed with a density of ρ_{MH}. The average number of MHs crossing out of the cell and the PA per unit time, r_{cell} and r_{PA}, respectively, are given by:

$$r_{cell} = \frac{\rho_{MH} l_{cell}}{\pi} \sum_{i=0}^{3} P_{env_i} V_i, \qquad r_{PA} = \frac{\rho_{MH} l_{PA}}{\pi} \sum_{i=0}^{3} P_{env_i} V_i$$

where l_{cell} and l_{PA} are the length of the cell perimeter and the PA perimeter, respectively. The average rates of cell updates and PA updates of an MH are obtained by:

$$\begin{aligned} \lambda_c &= \frac{r_{cell}}{(\frac{l_{cell}}{4})^2 \rho_{MH}} = \frac{16}{\pi l_{cell}} \sum_{i=0}^{3} P_{env_i} V_i \\ \lambda_{PA} &= \frac{r_{PA}}{(\frac{l_{PA}}{4})^2 \rho_{MH}} = \frac{16}{\pi l_{cell} \sqrt{N_{cell/PA}}} \sum_{i=0}^{3} P_{env_i} V_i \end{aligned}$$

Let r_1 be the time interval from the instant that the MH enters state i to the instant that the MH conducts the first BL-based registration in the state. Let $f_{r_1}(t)$ and $f_{T_i}(t)$ denote the density functions of the time interval r_1 and the sojourn time T_i, respectively. Then, the mean number of BL-based registrations $\bar{N}_{BL,i}$ is obtained by:

$$\begin{aligned} \bar{N}_{BL,i} &= \sum_{n=1}^{\infty} n Pr[N_{BL,i} = n] \\ &= \sum_{n=1}^{\infty} \frac{n}{2\pi j} \int_{\sigma - j\infty}^{\sigma + j\infty} \frac{F_{r_1}^*(\theta)[F_r^*(\theta)]^{n-1}[1 - F_r^*(\theta)]}{\theta} F_{T_i}^*(-\theta) d\theta \end{aligned} \tag{30}$$

where $F_{r_1}^*(\theta)$ and $F_{T_i}^*(\theta)$ denote the Laplace transforms of $f_{r_1}(t)$ and $f_{T_i}(t)$, respectively. Equation (30) is evaluated using the Residue theorem [26]. We define a cost function as the weighted sum of the rates of cell-based registration, PA-based registration, BL-based registration, and paging messages for the proposed scheme as follows:

$$C_{prop}^{tot} = C_{prop}^{reg} + C_{prop}^{pag} \tag{31}$$

$$C_{prop}^{reg} = C_{prop}^{cell} + C_{prop}^{PA} + C_{prop}^{BL} = w_{cell} \lambda_{prop}^{cell} + w_{PA} \lambda_{prop}^{PA} + w_{BL} \lambda_{prop}^{BL} \tag{32}$$

$$C_{prop}^{pag} = w_{pag} \lambda_{prop}^{pag} \tag{33}$$

where w_{cell}, w_{PA}, w_{BL}, and w_{pag} are weighting factors. If the registration interval and session holding time follow exponential distributions, an optimal value of the mean rate of BL-based registration λ_r^* that minimizes C_{prop}^{tot} is derived as:

$$\lambda_r^* = -(\lambda_i + \mu_{off}) + \sqrt{\frac{w_{pag} k \lambda_i \lambda_{off} N_{cell/PA}}{w_{BL}}} \tag{34}$$

The optimal rate of BL-based registration is determined by incoming session rate, the duration that an MH remains switched-off, the number of paging repetitions, the number of cells in PA, the switch-off rate, and the weighting factors w_{pag} and w_{BL}. We can also derive an optimal value of the number of cells in PA $N^*_{cell/PA}$ that minimizes C^{tot}_{prop} as:

$$N^*_{cell/PA} = \left(\frac{w_{PA}}{w_{pag}} \frac{\lambda_c}{2\lambda_i} \frac{P_4 + P_5}{P_4 + P_5 + kP_6} \right)^{2/3} \tag{35}$$

where the sum of steady state probabilities $P_4 + P_5$ is derived from Equations (19) and (20).

$$P_4 + P_5 = \frac{\lambda_{off}\mu_{off}}{\lambda_{off} + \mu_{off}} \frac{(\lambda_1 + \lambda_c)e^{-\lambda_1}}{\lambda_1(\lambda_1 + \lambda_c e^{-\lambda_1})} \left[1 - \frac{\lambda_s}{\lambda_s + \lambda_{off}} F^*_s(\lambda_{off}) \right]^{-1} \tag{36}$$

The optimal number of cells in PA is determined by incoming session rate, the cell-based registration rate, the number of paging repetitions, the weighting factors w_{PA} and w_{pag}, and the steady state probabilities $P_4 + P_5$ and P_6.

Since the conventional MIP protocol [1-2] does not distinguish between active and idle MHs, the value of attention timer T_A approaches ∞. The rates of cell-based registration, BL-based registration, and paging messages for the conventional scheme are obtained as:

$$\lambda^{cell}_{conv} = \rho_{MH} A_{tot} (P_1 + P_2 + \lim_{T_A \to \infty} P_3)\lambda_c = \rho_{MH} A_{tot} \sum_{i=1}^{5} P_i \lambda_c \tag{37}$$

$$\lambda^{BL}_{conv} = \rho_{MH} A_{tot} \sum_{i=1}^{5} P_i \frac{\bar{N}_{BL,i}}{\bar{T}_i} \tag{38}$$

$$\lambda^{pag}_{conv} = \rho_{MH} A_{tot} k P_6 \lambda_i \tag{39}$$

If an MH is in the off/attached state, the MH does not respond to paging for incoming sessions. We consider this unsuccessful paging in the conventional MIP protocol. We define the network cost for the conventional scheme as the weighted sum of the rates of cell-based registration, BL-based registration, and paging messages as follows:

$$C^{tot}_{conv} = C^{reg}_{conv} + C^{pag}_{conv} \tag{40}$$

$$C^{reg}_{conv} = C^{cell}_{conv} + C^{BL}_{conv} = w_{cell}\lambda^{cell}_{conv} + w_{BL}\lambda^{BL}_{conv} \tag{41}$$

$$C^{pag}_{conv} = w_{pag}\lambda^{pag}_{conv} \tag{42}$$

From Equations (26–33) and (37–42), the relationship of the registration cost between the proposed and conventional schemes is expressed as $C^{reg}_{prop} \leq C^{reg}_{conv}$ if $w_{cell} = w_{PA}$. Since the conventional scheme considers only unsuccessful paging for the off/attached MHs, the relationship of the paging cost between the proposed and conventional schemes is obtained by $C^{pag}_{prop} \geq C^{pag}_{conv}$.

4. Numerical Examples

The effects of various input parameters on the steady state probabilities and power consumption of the proposed and conventional schemes are investigated. The values of input parameters assumed for numerical examples are shown in Table 1 [14–16], [27–29].

Table 1. Input Parameters.

Parameter	**Value**
λ_i	1 (/h)
λ_o	1 (/h)
μ_s	3,600/300 (/h)
λ_c	4 (/h)
λ_{PA}	$\lambda_c/\sqrt{N_{cell/PA}}$ (/h)
$N_{cell/PA}$	16
T_A	120/3,600 (h)
λ_r	1 (/h)
λ_{off}	1/4 (/h)
μ_{off}	1 (/h)
Pc_1	1.10 (W)
Pc_2	0.90 (W)
Pc_3	0.80 (W)
Pc_4	0.70 (W)
Pc_5	0.01 (W)
Pc_6	0 (W)
Pc_7	0 (W)

Figure 3 shows the effect of session arrival rate λ_s on the steady state probabilities. The session arrival rate λ_s is expressed as $\lambda_s = \lambda_i + \lambda_o$. The higher the session arrival rate, the higher the transition probabilities P_{31}, P_{41}, P_{51} P_{32}, P_{42}, and P_{52} due to the high rate of incoming or outgoing session arrivals. Therefore, as the value of λ_s increases, the probability P_1+P_2 increases, but the probability P_5 decreases.

Figure 4 shows the effect of session arrival rate λ_s on the power consumption for the proposed and conventional schemes. The power consumption is calculated as the energy consumption divided by time. The energy consumption for the proposed and conventional schemes is calculated using Equations (23) and (25), respectively. The power consumption for the proposed and conventional schemes increases as the value of λ_s increases because it is more likely that MHs stay in the *transmitting* and *receiving* states as the value of λ_s increases. The MH power consumption in the proposed scheme is approximately 0.1126 W, 0.1763 W and 0.4756 W at the session arrival rate λ_s = 1(/h), λ_s = 2(/h), and λ_s = 10(/h), respectively. The MH power consumption for the conventional scheme is approximately 0.6521 W, 0.6625 W and 0.7119 W at λ_s = 1(/h), λ_s = 2(/h), and λ_s = 10(/h), respectively. Thus, for $2 \leq \lambda_s \leq 10$, the power consumption of the proposed scheme is reduced by about 33.2% $\sim$ 73.4% compared with the conventional scheme. Furthermore, if the session arrival rate is low ($\lambda_s \leq 1$), the proposed scheme can save about 82.7% of the battery power consumption at the MH compared with the conventional scheme in Mobile IP-based wireless networks.

Figure 3. The effect of λ_s on the steady state probabilities.

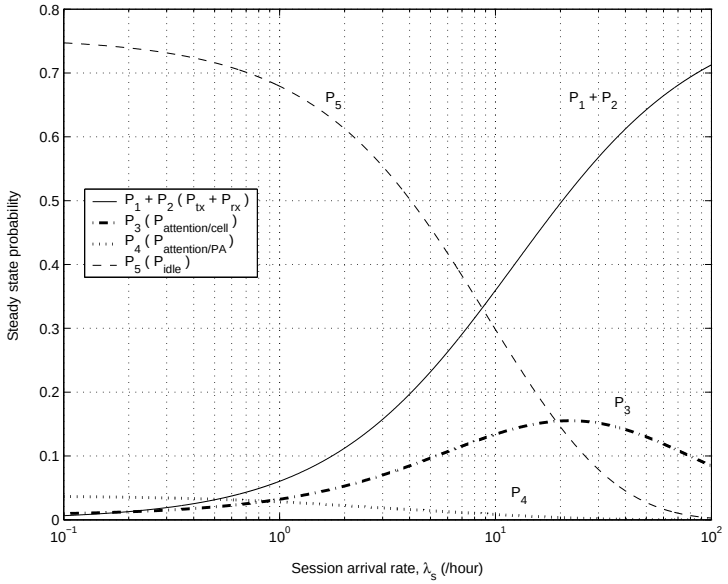


Figure 4. The comparison of the power consumption in the proposed and conventional schemes for varying the values of λ_s.

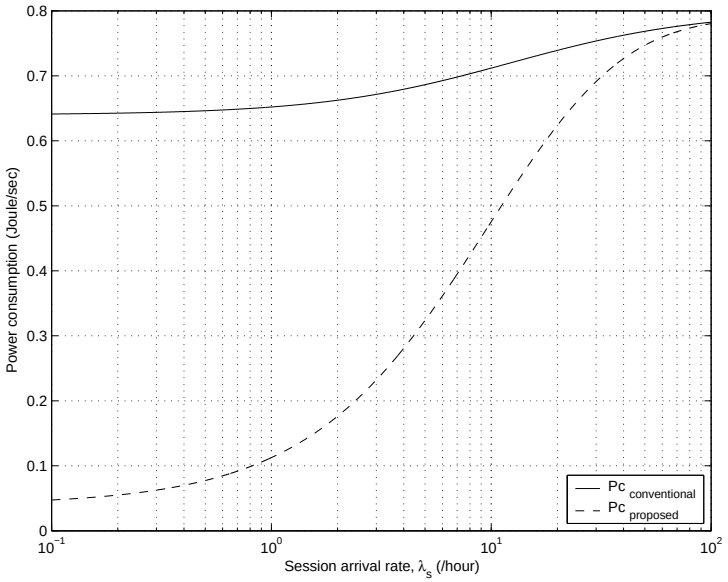


Figure 5 shows the effect of switch-off rate λ_{off} on the steady state probabilities. As the switch-off rate λ_{off} increases, the probabilities P_6 and P_7 increase, but the probabilities P_1, P_2, P_3, P_4, and P_5 decrease. Because it is more likely that MHs stay in the *off/attached* state and *detached* state as the switch-off rate λ_{off} increases. Figure 6 compares the power consumption of the proposed scheme with that of the conventional scheme for varying the values of λ_{off} and μ_{off}. When an MH is in the *off/attached* state or *detached* state, the MH does not consume power because the MH is powered off. As the switch-off rate λ_{off} increases and the mean switch-off duration $1/\mu_{off}$ increases, the power consumption for the proposed and conventional schemes decreases.

Figure 5. The effect of λ_{off} on the steady state probabilities.

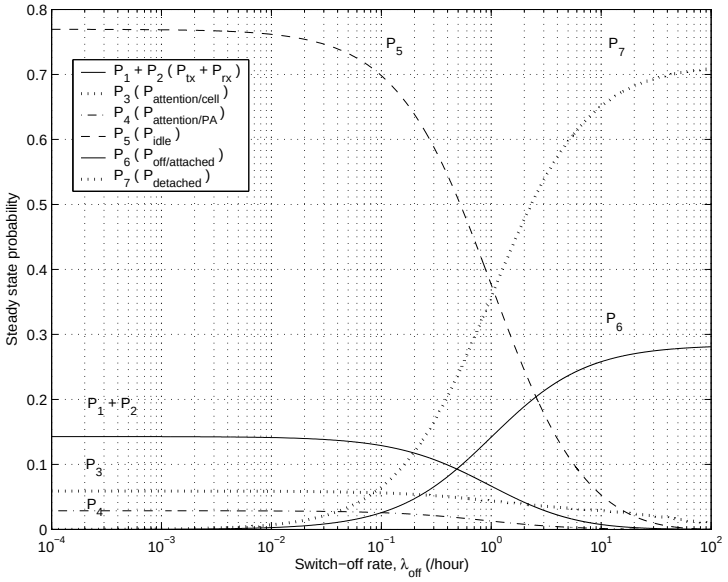


Figure 6. The comparison of the power consumption in the proposed and conventional schemes for varying the values of λ_{off} and μ_{off}.

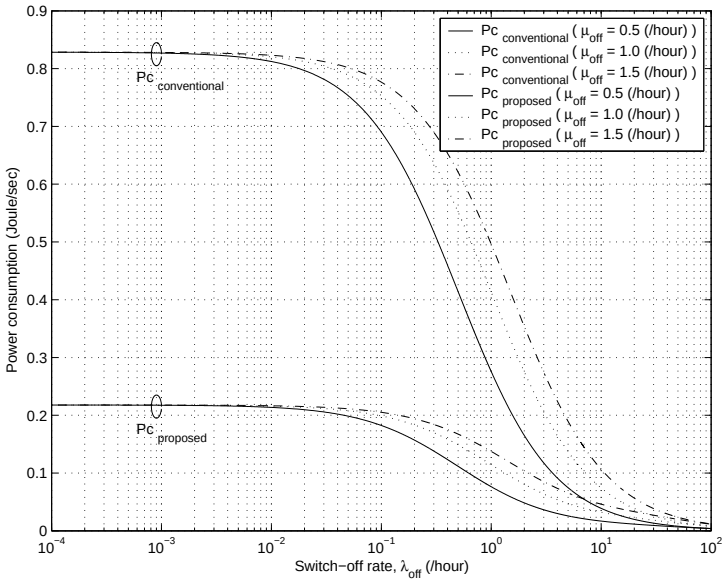


Figure 7 shows the effect of attention timer value T_A on the power consumption of the proposed scheme for various values of BL-based registration rate λ_r if the registration interval is fixed (solid line) or exponentially (dashed line) distributed. As the values of T_A and λ_r increase, power consumption of the proposed scheme increases because the probability P_5 that an MH stays in the *idle* state decreases. An MH battery's power is saved more as the value of attention timer T_A decreases. However, the value of T_A needs to be determined by considering the incoming session rate and the data session delay. The results show that the power consumption of the proposed scheme depends on the distribution of the registration intervals. The fixed registration intervals are better than the exponential registration intervals from the viewpoint of the power-saving effect of the proposed scheme.

Figure 7. The effect of T_A on the power consumption of the proposed scheme for various values of λ_r if the interval of binding-lifetime-based registration is fixed (solid line) or exponentially (dashed line) distributed.

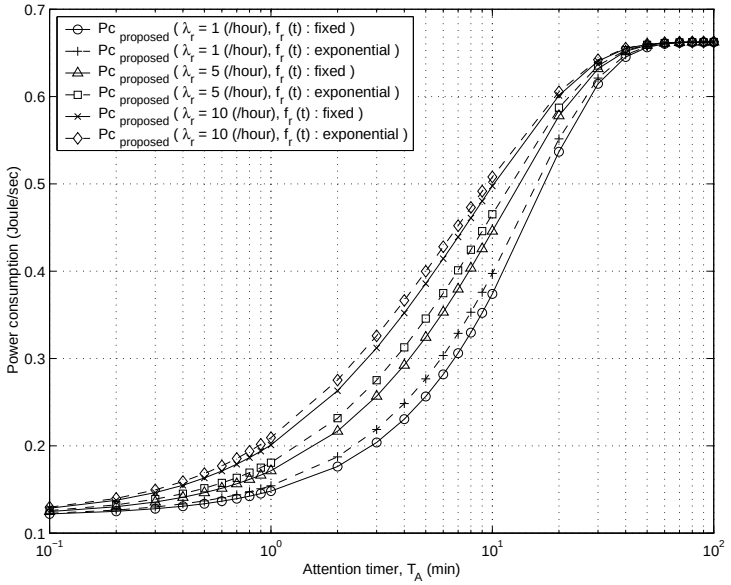
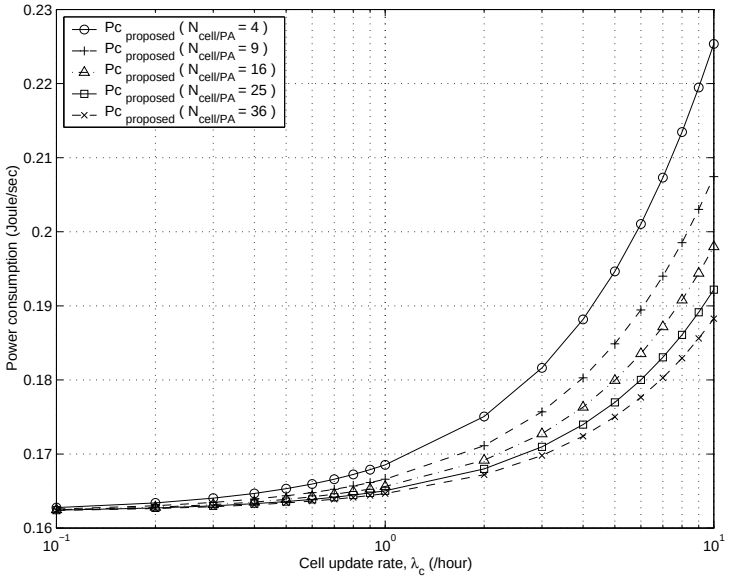


Figure 8 shows the effect of cell update rate λ_c on the power consumption of the proposed scheme for various values of $N_{cell/PA}$. As MH mobility increases, both the cell update rate λ_c and the power consumption increases because the probability P_5 that the MH stays in the *idle* state decreases as the cell update rate λ_c increases. As the number of cells in PA $N_{cell/PA}$ decreases, both the PA update rate λ_{PA} and the power consumption increases.

Figure 8. The effect of λ_c on the power consumption of the proposed scheme for various values of $N_{cell/PA}$.



The effects of various input parameters on the network cost of the proposed scheme in IP-based wireless networks are investigated. The values of input parameters assumed for numerical examples are shown in Table 2 [23-25].

Table 2. Input Parameters.

Parameter	Value	Parameter	Value
λ_i	1/2 (/h)	λ_o	1/2 (/h)
μ_s	10 (/h)	T_A	1/15 (h)
λ_{off}	1/4 (/h)	μ_{off}	1/3 (/h)
T_r	1 (h)	w_{reg}^{cell}, w_{reg}^{PA}	1
k	3	w_{reg}^{BL}, w_{pag}	1
ρ_{MH}	100 $(/km^2)$	l_{cell}	2 (km)
V_0	0 (km/hr)	P_{env0}	0.40
V_1	2 (km/hr)	P_{env1}	0.25
V_2	4 (km/hr)	P_{env2}	0.20
V_3	60 (km/hr)	P_{env3}	0.15

Figure 9 shows the effect of $N_{cell/PA}$ on the network cost of the proposed scheme which consists of cell update cost C_{prop}^{cell}, PA update cost C_{prop}^{PA}, BL-based registration cost C_{prop}^{BL}, and paging cost C_{prop}^{pag}. As the number of cells in PA $N_{cell/PA}$ increases, the PA update cost decreases due to infrequent crossing out of the PA, while the paging cost increases due to paging messages for the large number of cells in PA. The cell update cost and the BL-based registration cost are fixed with various numbers of cells in PA $N_{cell/PA}$ according to Equations (26) and (28).

Figure 9. The effect of $N_{cell/PA}$ on the network cost of the proposed scheme.

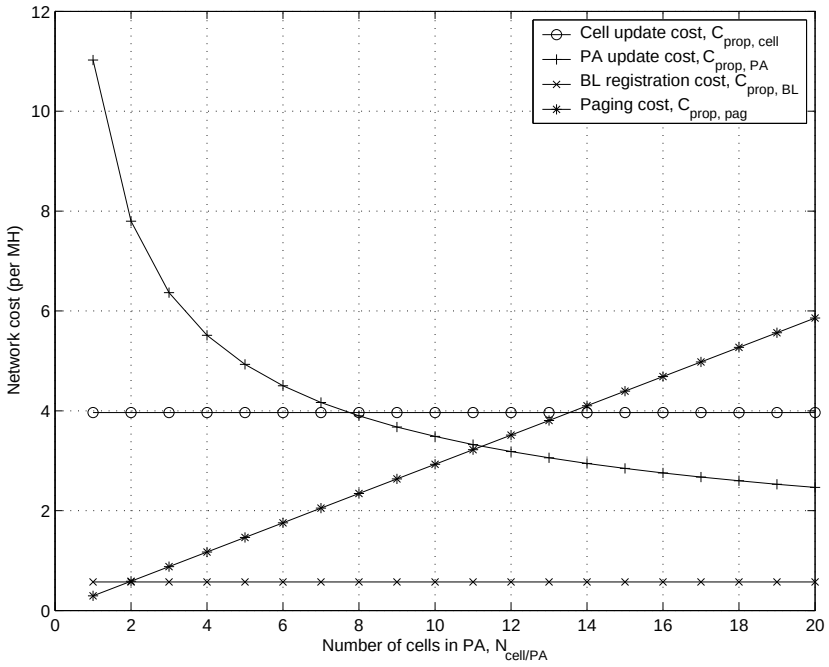
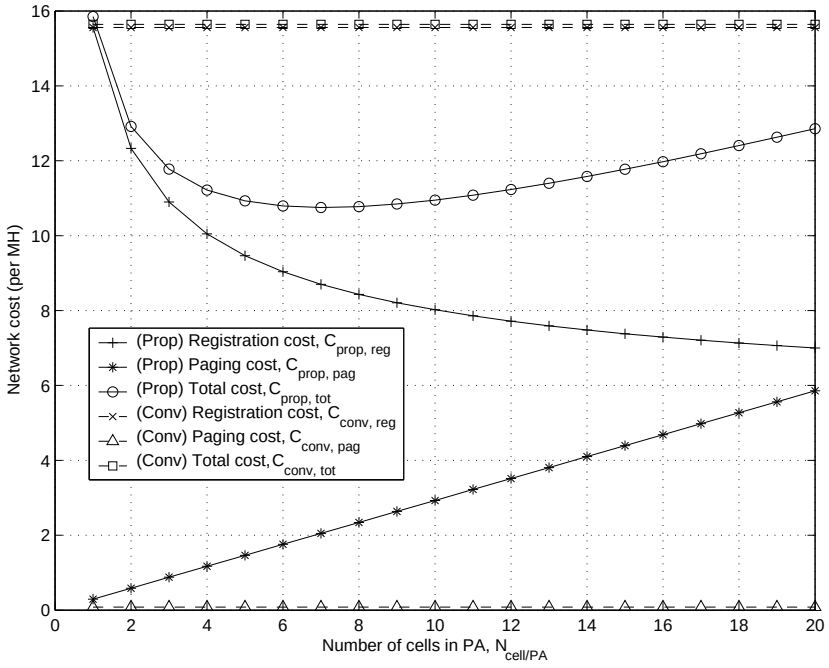


Figure 10 shows the effect of $N_{cell/PA}$ on registration cost C_{prop}^{reg}, C_{conv}^{reg}, paging cost C_{prop}^{pag}, C_{conv}^{pag}, and total network cost C_{prop}^{tot}, C_{conv}^{tot} for the proposed and conventional schemes. The network costs for the conventional scheme are fixed with varying $N_{cell/PA}$ according to Equations (37–42). The numerical results show that $C_{prop}^{pag} \geq C_{conv}^{pag}$ and $C_{prop}^{reg} \leq C_{conv}^{reg}$ when $w_{cell} = w_{PA}$. For the proposed scheme, the optimal number of cells in PA $N_{cell/PA}^{*}$ can exist. The result shows that total network cost with the input parameters is a minimum value at $N_{cell/PA}^{*} = 7$ which is consistent with Equation (35).

Figure 10. The optimal number of cells in paging area (PA) $N_{cell/PA}^{*}$ of the proposed scheme.



We define the combined network and power cost for the proposed scheme C_{prop}^{comb} and that for the conventional scheme C_{conv}^{comb} as:

$$C_{prop}^{comb} = w_{net}C_{prop}^{tot} + w_{pow}Pc_{prop} = w_{net}C_{prop}^{tot} + w_{pow}E_{prop}/t \quad (43)$$

$$C_{conv}^{comb} = w_{net}C_{conv}^{tot} + w_{pow}Pc_{conv} = w_{net}C_{conv}^{tot} + w_{pow}E_{conv}/t \quad (44)$$

where w_{net} and w_{pow} are weighting factors for network cost and power consumption, respectively. Figure 11 shows the combined network and power cost C_{prop}^{comb} for the proposed scheme with varying the values of $N_{cell/PA}^{*}$ and w_{pow}. As the weighting factor w_{pow} increases as $1, 25$, and 50 with fixed value of w_{net}, the optimal number of cells in PA $N_{cell/PA}^{*}$ increases as $7, 9$, and 11 for the combined network and power cost. It is because the MH power consumption for the proposed scheme decreases as $N_{cell/PA}$ increases as shown in Figure 8.

Figure 12 shows the effect of mean rate of BL-based registration λ_r on the network cost of the proposed scheme which consists of cell update cost C_{prop}^{cell}, PA update cost C_{prop}^{PA}, BL-based registration cost C_{prop}^{BL}, and paging cost C_{prop}^{pag}. As the BL-based registration rate λ_r increases, the BL-based registration cost increases and the paging cost decreases due to the frequent BL-based registrations. The rates of cell-based registration and PA-based registration are fixed with various values of λ_r according to Equations (26) and (27).

Figure 11. Combined network and power cost for the proposed scheme for varying the values of $N_{cell/PA}$.

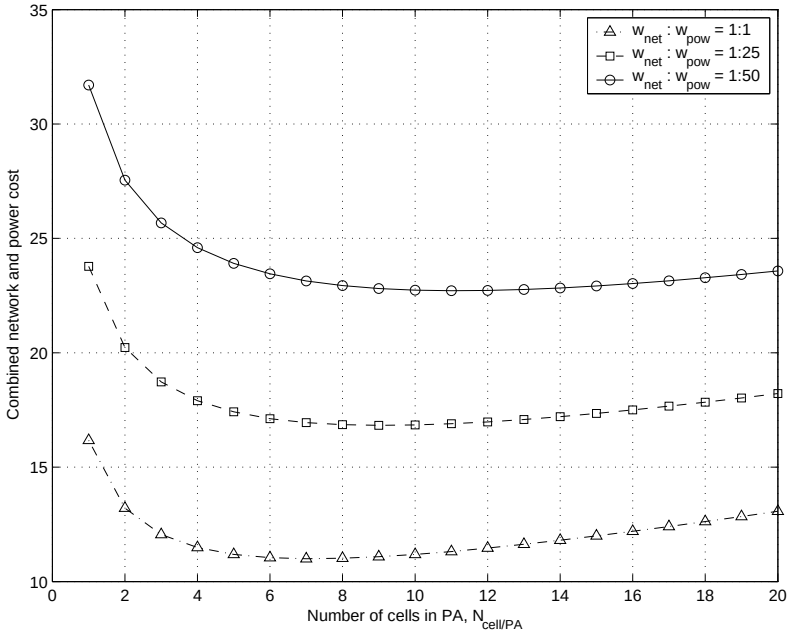


Figure 12. The effect of λ_r on the network cost of the proposed scheme.

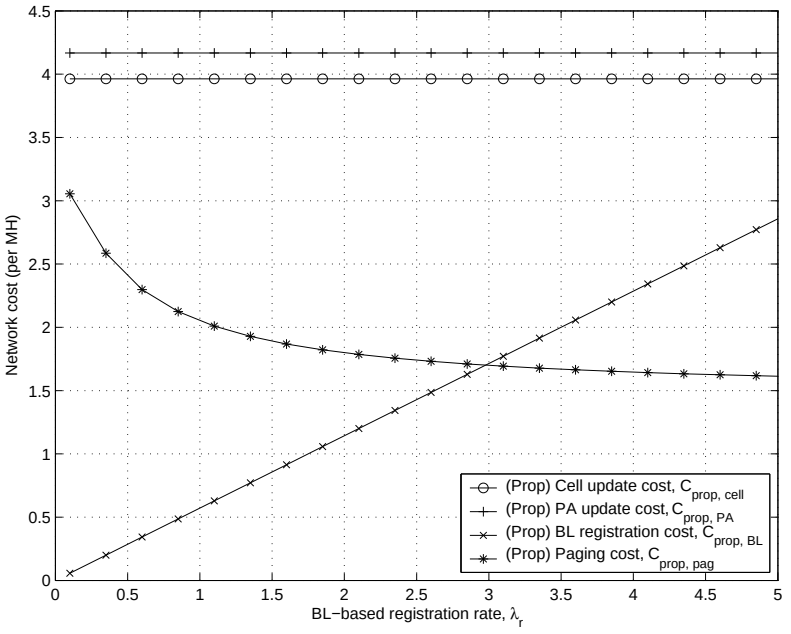


Figure 13 shows the effect of λ_r on the total network cost C_{tot} and the optimal BL-based registration rate λ_r^* for two types of distributions of registration intervals, exponential (dashed line) and fixed (solid line) distributions. The result shows that the distribution of the BL-based registration intervals affects the network cost. If the BL-based registration intervals follow an exponential distribution, the total network cost C_{tot} is a minimum value of 10.98 at $\lambda_r^* = 0.8$ which is consistent with Equation (34). When the fixed BL-based registration intervals are utilized, the minimum network cost is 10.74 at

$\lambda_r^* = 0.8$. Therefore, the fixed BL-based registration intervals are preferred over the exponential BL-based registration intervals since the fixed BL-based registration intervals yield a lower network cost in the proposed scheme for IP-based wireless networks.

Figure 14 shows the combined network and power cost C_{prop}^{comb} for the proposed scheme with exponential BL-based registration intervals for various values of λ_r and w_{pow}. As shown in Figure 7, the power consumption of MHs for the proposed scheme increases as λ_r increases. Hence, as the weighting factor w_{pow} increases as 1, 10, and 20 with fixed value of w_{net}, the optimal BL-based registration rate λ_r^* for the combined network and power cost decreases as 0.8, 0.7, and 0.6.

Figure 13. The optimal binding-lifetime-based registration rate λ_r^* of the proposed scheme.

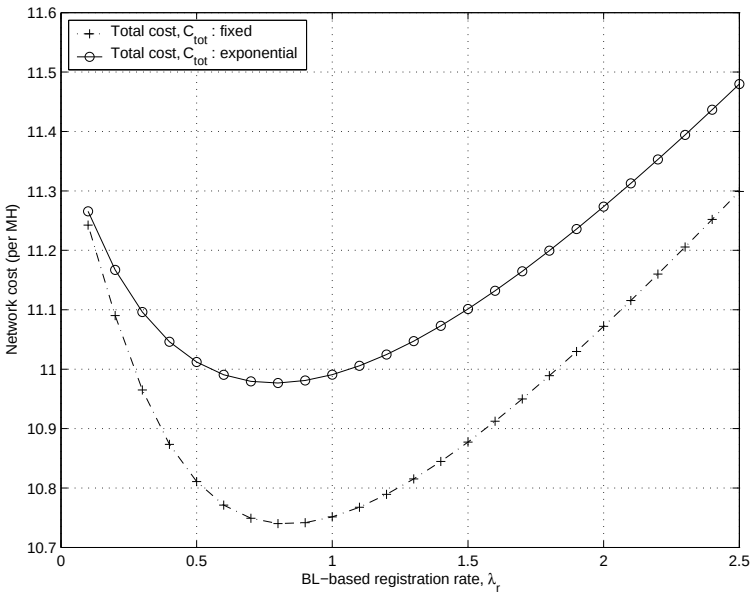
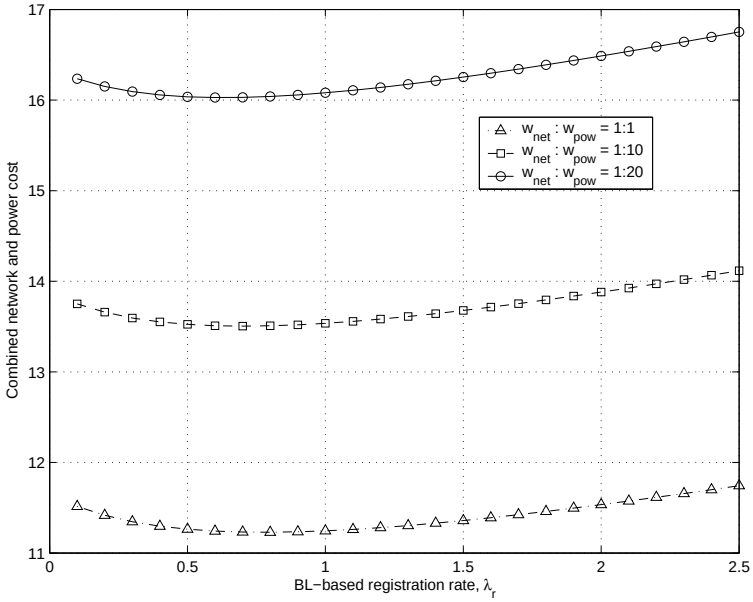


Figure 14. Combined network and power cost of the proposed scheme for varying the values of λ_r.



5. Conclusions

An energy-efficient mobility management scheme was proposed to reduce MH power consumption in IP-based wireless networks. The proposed scheme manages the following seven MH states, including transmitting, receiving, attention/cell-connected, attention/PA-connected, idle, off/attached, and detached states, to efficiently manage battery power, radio resources, and network load. The MH state transition behavior was modeled. We derived the stationary probabilities and steady state probabilities of the MH states for the proposed and conventional schemes in IP-based wireless networks in compact form. The effects of various input parameters on the MH steady state probabilities and power consumption were investigated in the proposed scheme compared to the conventional scheme with consideration of exponential and fixed distributions on interval of BL-based registration. The proposed scheme yielded significant power savings compared with the conventional mobility management scheme for Mobile IP based wireless networks. Network costs such as cell updates, PA updates, BL-based registrations, and paging messages were analyzed in the proposed and conventional schemes for IP-based wireless networks. The optimal values of PA size and registration interval were derived to minimize the network cost of the proposed scheme. The effects of various input parameters on the network cost were investigated. We also investigated the combined network and power cost with various weighting factors for the proposed and conventional schemes. These analytical results provide guidelines to select proper system parameters. The results can be utilized to analyze the performance of mobility management schemes in IP-based wireless networks.

Acknowledgements

This work was supported in part by the Korea Research Foundation Grant funded by the Korean Government (KRF-2008-357-D00181) and in part by the Research Grant of Kwangwoon University in 2011.

References

1. Perkins, C. *IP Mobility Support for IPv4*; IETF RFC 3344; The Internet Society: Washington, DC, USA, August 2002.
2. Johnson, D.B.; Perkins, C.; Arkko, J. *Mobility Support in IPv6*; IETF RFC 3775; The Internet Society: Washington, DC, USA, June 2004.
3. Reinbold, P.; Bonaventure, O. IP micro-mobility protocols. *IEEE Commun. Surv. Tutor.* **2003**, *5*, 40–56.
4. Ramjee, R.; Varadhan, K.; Salgarelli, L.; Thuel, S.R.; Wang, S.-Y.; La Porta, T. HAWAII: A domain-based approach for supporting mobility in wide-area wireless networks. *IEEE/ACM Trans. Netw.* **2002**, *10*, 396–410.
5. Zhang, X.; Castellanos, J.G.; Campbell, A.T. P-MIP: Paging extensions for mobile IP. *Mob. Netw. Appl.* **2002**, *7*, 127–141.
6. Chung, Y.W.; Sung, D.K.; Aghvami, A.H. Steady state analysis of P-MIP mobility management. *IEEE Commun. Lett.* **2003**, *7*, 278–280.

7. Soliman, H.; Castelluccia, C.; Malki, K.E.; Bellier, L. *Hierarchical Mobile IPv6 Mobility Management (HMIPv6)*; IETF RFC 4140; The Internet Society: Washington, DC, USA, August 2005.
8. Koodli, R. *Fast Handover for Mobile IPv6*; IETF RFC 4068; The Internet Society: Washington, DC, USA, July 2005.
9. Kempf, J. *Problem Statement for Network-Based Localized Mobility Management (NETLMM)*; IETF RFC 4830; The Internet Society: Washington, DC, USA, April 2007.
10. Kempf, J. *Goals for Network-Based Localized Mobility Management (NETLMM)*; IETF RFC 4831; The Internet Society: Washington, DC, USA, April 2007.
11. Gundavelli, S.; Leung, K.; Devarapalli, V.; Chowdhury, K.; Patil, B. *Proxy Mobile IPv6*; IETF RFC 5213; The Internet Society: Washington, DC, USA, August 2008.
12. Kong, K.; Han, Y.; Shin, M.; Yoo, H.; Lee, W. Mobility management for all-IP mobile networks: Mobile IPv6 *vs.* proxy mobile IPv6. *IEEE Wirel. Commun.* **2008**, *15*, 36–45.
13. Zhou, H.; Zhang, H.; Qin, Y.; Wang, H.-C.; Chao, H.-C. A proxy mobile IPv6 based global mobility management architecture and protocol. *Mob. Netw. Appl.* **2010**, *15*, 530–542.
14. Kwon, S.-J.; Nam, S.Y.; Hwang, H.Y.; Sung, D.K. Analysis of a mobility management scheme considering battery power conservation in IP-based mobile networks. *IEEE Trans. Veh. Technol.* **2004**, *53*, 1882–1890.
15. Hwang, H.Y.; Kwon, S.-J.; Chung, Y.W.; Sung, D.K. A mobility management scheme for reducing power consumption in IP-based wireless networks. In *Proceedings of the GLOBECOM*, Taipei, Taiwan, November 2002; pp. 2979–2983.
16. Hwang, H.Y.; Kwon, S.-J.; Chung, Y.W.; Sung, D.K.; Park, S. Steady state analysis of an energy efficient mobility management scheme in IP-based wireless networks. In *Proceedings of the FGIT, LNCS 6485*, Jeju Island, Korea, December 2010; pp. 145–153.
17. Ross, S.M. *Stochastic Process*; John Wiley & Sons: Hoboken, NJ, USA, 1996.
18. Lin, P.; Lin, Y.-B. Channel allocation for GPRS. *IEEE Trans. Veh. Technol.* **2001**, *50*, 375–387.
19. Yang, S.-R. Dynamic power saving mechanism for 3G UMTS system. *Mob. Netw. Appl.* **2007**, *12*, 5–14.
20. Lin, Y.-B. Eliminating tromboning mobile call setup for international roaming users. *IEEE Trans. Wirel. Commun.* **2009**, *8*, 320–325.
21. Lin, Y.-B.; Tsai, M.-H.; Dai, H.-W.; Chen, Y.-K. Bearer reservation with preemption for voice call continuity. *IEEE Trans. Wirel. Commun.* **2009**, *8*, 2716–2725.
22. Watanabe, Y.; Yabusaki, M. Mobility/traffic adaptive location management. *IEICE Trans. Commun.* **2002**, *E85-B*, 2076–2082.
23. *Methodology for the Calculation of IMT-2000 Terrestrial Spectrum Requirement*; Rec. ITU-R, M.1390; International Telecommunication Union (ITU): Geneva, Switzerland, May 2000.
24. *Spectrum Requirements for IMT-2000*; Rep. ITU-R, M.2023; International Telecommunication Union (ITU): Geneva, Switzerland, May 2000.
25. *Methodology for Calculation of Spectrum Requirements for the Future Development of IMT-2000 and Systems beyond IMT-2000 from the Year 2010 Onwards*; Rec. ITU-R, M.1768; International Telecommunication Union (ITU): Geneva, Switzerland, June 2006.

26. Fang, Y.; Chlamtac, I.; Lin, Y.-B. Portable movement modeling for PCS networks. *IEEE Trans. Veh. Technol.* **2000**, *49*, 1356–1363.
27. Shih, E.; Cho, S.-H.; Nathan, I.; Min, R.; Sinha, A.; Wang, A.; Chandrakasan, A. Physical layer driven protocol and algorithm design for energy-efficient wireless sensor networks. In *Proceedings of the MobiCom*, Rome, Italy, 16–21 July 2001; pp. 272–287.
28. Feeney, L.M.; Nilsson, M. Investigating the energy consumption of a wireless network interface in an *ad hoc* networking environment. In *Proceedings of the INFOCOM*, Anchorage, AK, USA, 22–26 April 2001; Volume 3, pp. 1548–1557.
29. Shih, E.; Bahl, P.; Sinclair, M.J. Wake on wireless: An event driven energy saving strategy for battery operated devices. In *Proceedings of the MobiCom*, Atlanta, GA, USA, 23–28 September 2002; pp. 160–171.

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